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Assessment of the REmote MInefield Detection System (REMIDS)

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June 1998

Approved for public release;
distribution unlimited.

IDA Document D-2158

Log: H 98-001571

This work was conducted under contracts DASW01 94 C 0054/ DASW01 97 C 0056, Task T-AM2-1528, for the Deputy Under Secretary of Defense for Environmental Security. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

PREFACE

This paper was prepared for the Deputy Under Secretary of Defense for Environmental Security under a task entitled "Assessment of Traditional and Emerging Approaches to the Detection and Identification of Surface and Buried Unexploded Ordnance." This paper fulfills subtask h of that task.

We would like to thank Tom Altshuler and David Sparrow whose comments and suggestions greatly improved the quality of this paper.

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A. THE REMOTE MINEFIELD DETECTION SYSTEM

Millions of acres of government land are contaminated with unexploded ordnance (UXO), a result of years of testing and training in the armed forces. As part of the effort to prepare some of this land for use other than as test ranges, programs are underway to develop methods to safely and reliably detect UXO so that the contaminated sites may be cleaned before realignment.

This report describes the REmote MInefield Detection System (REMIDS) developed by the U.S. Army Engineer Waterways Experiment Station to detect surface UXO and reviews the performance of REMIDS in tests at the Yuma Proving Ground, Arizona, and at Fort Rucker, Alabama.

The principle behind REMIDS is to enhance the discrimination of surface UXO by relying on multiple signatures: surface UXO may exhibit a unique *combination* of reflectance, polarization, temperature, and footprint (shape) compared to natural objects in the UXO's surroundings. Discrimination based on four signatures is in principle greater than that based on fewer signatures.

The REMIDS hardware consists of an airborne line scanner with sensors that measure the reflectance, polarization, and thermal response in 710 round "spots," each of which subtends 1.25 mrad. (The reflectance and polarization sensors are active and utilize a Nd:YAG laser; the thermal response sensor is passive.) The 710 spots partially overlap and are arranged in a line such that the total field of view of one scan line is 1.25 mrad by 40 deg. The scan rate of the device is 350 lines per second. Thus, when the REMIDS is flown in a helicopter at an altitude of 130 ft and a speed of 32 knots, each of the three sensors will digitize its own map of the ground level with a pixel size of 1.9 in. × 1.9 in.

Analysis of the REMIDS digitized data is performed in three stages. In the first stage, a computer classifies each pixel as from a UXO candidate or from background. (At some sites, the spectral return of the background is sufficiently distinct from all UXO that this stage is the only step required to achieve satisfactory performance.) In the second stage, a requirement on the minimum size of objects (i.e., on the minimum number of

contiguous pixels) is imposed. In the last stage, an operator views all potential candidates and determines if they are UXO or background. The operator may also classify the type of UXO.

B. ADVANTAGES AND LIMITATIONS

The REMIDS technology has both advantages and limitations over other systems in locating UXO. As an airborne system based on current technology, it promises several advantages:

- It will be of minimal risk to the personnel performing the measurements.
- The method may be able to cover large tracts of land in a relatively short time.
- The assessments possibly may be done at a reasonable cost.
- It could be used to locate "potential hot regions" for buried UXO in cases when surface debris is correlated with buried UXO.

The technology has important limitations, however:

- REMIDS relies on direct line of sight for all three sensors. It would be risky to rely on this technology in areas with broad-leaf vegetation or trees. Further, any buried UXO will not be detected by REMIDS. Even a thick layer of dust could compromise a sensor's reading, leading to a lower detection probability.
- Because different types of UXO will have different reflectance, polarization, and thermal signatures, a priori knowledge of the ordnance type is important to calibrate REMIDS. Thus, REMIDS may not reliably detect unexpected or uncharacterized ordnance.
- REMIDS may not reliably detect small ordnance when the background has characteristics similar to the UXO. In tests performed at the Yuma Proving Ground, it was necessary to require that UXO candidates contain a minimum number of contiguous pixels to minimize the background contribution to the candidate pool.
- Currently, REMIDS relies heavily on the operator to discriminate UXO from background in challenging environments. In the last stage of the Yuma data analysis, the operator determined candidates based on the shape of objects as viewed by a particular sensor channel, usually polarization. This raises questions concerning operator training and operator-to-operator variability.

C. SYSTEM PERFORMANCE

The REMIDS system was tested at a 2,400 m^2 test site at Fort Rucker, Alabama, and at a 0.5 km^2 test site at Yuma Proving Ground in Arizona. The performance of this

system is site dependent. Some sites consist of backgrounds that render discrimination based solely on the three spectral returns impossible. If the background is grassy, it is quite likely that a P_d of at least 90 percent is achievable with very low false-alarm rates using only the spectral information (see Figure ES-1, the Fort Rucker performance curve).

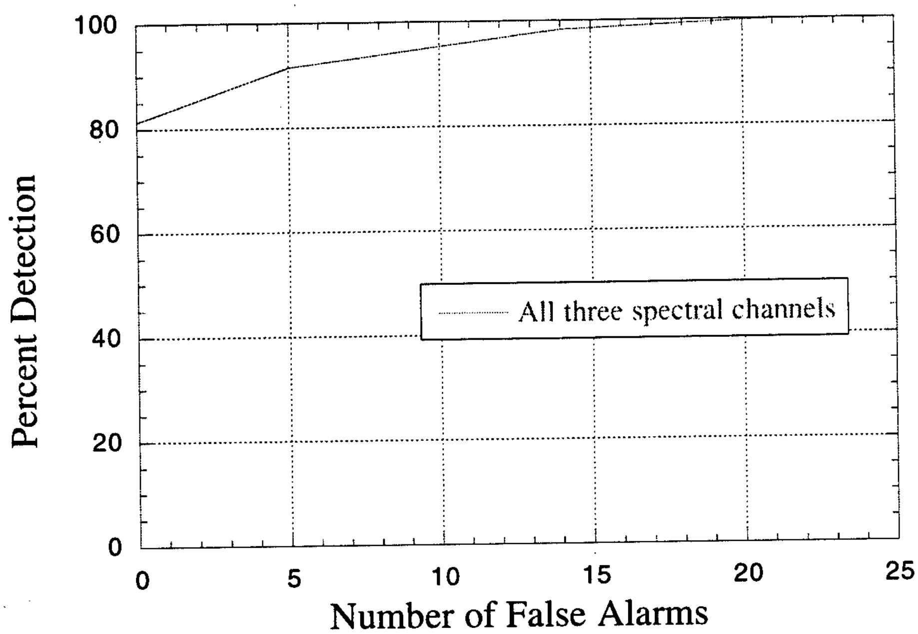

Figure ES-1. Receiver-Operator Characteristic (ROC) Curve for Fort Rucker: All Targets

On the other hand, at sites like Yuma, such performance is probably impossible with just the spectral information. However, with a knowledgeable operator, fair-to-good performance can be expected once a minimum size requirement is established for potential UXO candidates. Figure ES-2 shows the probability of detection as a function of radius surrounding the target at Yuma, where only ordnance items greater than 4 pixels in size were included in the target baseline. The position accuracy of the REMIDS system at Yuma was determined to be 1.55 m in the easting direction and 2.18 m in the northing direction, and a very low false-alarm rate of 41 per km^2 was achieved. We note that the performance indicated in Figure ES-2 is probably a lower-bound estimate for the potential of this system, because there were some areas of the site that the helicopter did not fly over, and these "holiday areas" contained an unknown number of targets. On the other hand, the target recognition capabilities of the operator played a crucial role in the performance of this system at Yuma, and it is not known how much P_d will vary with operator experience and training.

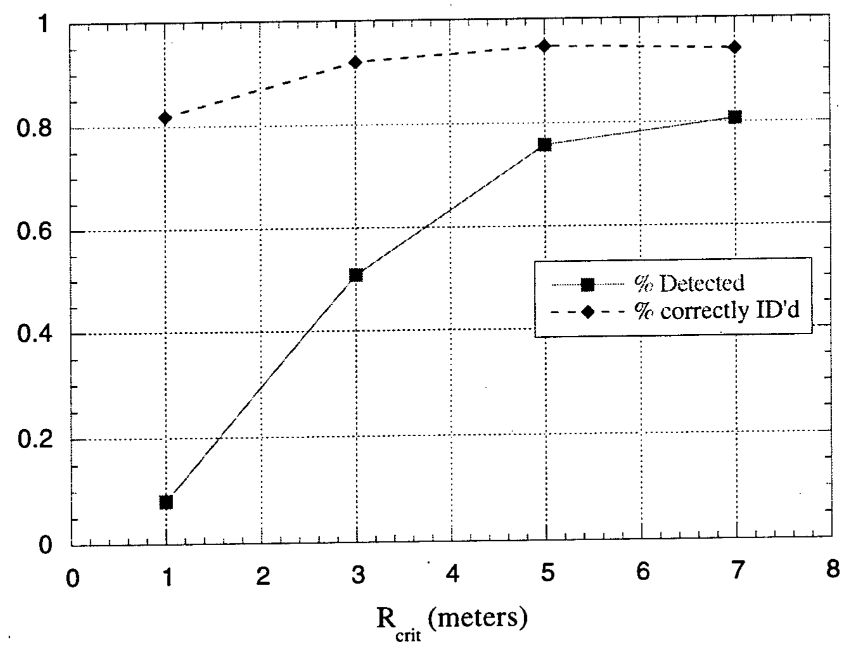

Figure ES-2. REMIDS Performance at Yuma

I. INTRODUCTION

Millions of acres of government land are contaminated with unexploded ordnance (UXO), a result of years of testing and training in the armed forces. As part of the effort to prepare some of this land for use other than as test ranges, programs are underway to develop methods to safely and reliably detect UXO so that the contaminated sites may be cleaned before realignment.

This report describes the REmote MInefield Detection System (REMIDS) developed by the U.S. Army Engineer Waterways Experiment Station to detect surface UXO, and reviews the performance of REMIDS in tests at the Yuma Proving Ground, Arizona, and at Fort Rucker, Alabama.

The principle behind REMIDS is to enhance the discrimination of surface UXO by relying on multiple signatures: surface UXO may exhibit a unique *combination* of reflectance, polarization, temperature, and footprint (shape), compared to natural objects in the UXO's surroundings. Discrimination based on four signatures is in principle greater than that based on fewer signatures.

The REMIDS hardware consists of an airborne line scanner with sensors that measure the reflectance, polarization, and thermal response in 710 round "spots," each of which subtend 1.25 mrad. (The reflectance and polarization sensors are active and utilize a Nd:YAG laser; the thermal response sensor is passive.) The 710 spots partially overlap and are arranged in a line such that the total field of view of one scan line is 1.25 mrad by 40 deg. The scan rate of the device is 350 lines per second. Thus, when the REMIDS is flown in a helicopter at an altitude of 130 ft and a speed of 32 knots, each of the three sensors will digitize its own map of the ground level with a pixel size of 1.9 in. $\times$ 1.9 in.

Analysis of the REMIDS digitized data is performed in three stages. In the first stage, a computer classifies each pixel as from a UXO candidate or from the background. In the second stage, a requirement on the minimum size of objects (i.e., on the number of contiguous pixels) is imposed. In the last stage, an operator views all potential candidates and determines if they are UXO or background. The operator may also classify the type of UXO.

The REMIDS technology has both advantages and limitations in locating UXO. As an airborne system based on current technology, it promises three advantages:

- It will be of minimal risk to the personnel performing the measurements.
- The method may be able to cover large tracts of land in a relatively short time.
- The assessments possibly may be done at a reasonable cost.

The technology has important limitations, however:

1. REMIDS relies on direct line of sight for all three sensors. It would be risky to rely on this technology in areas with broad-leaf vegetation or trees. Further, any buried UXO will not be detected by REMIDS. Even a thick layer of dust could compromise a sensor's reading, leading to a lower detection probability.
2. Because different types of UXO will have different reflectance, polarization, and thermal signatures, a priori knowledge of ordnance type is important to calibrate REMIDS. Thus, REMIDS may not reliably detect unexpected or uncharacterized ordnance.
3. REMIDS may not reliably detect small ordnance when the background has characteristics similar to the UXO. In tests performed at the Yuma Proving Ground, it was necessary to require that UXO candidates contain a minimum number of contiguous pixels in order to minimize the background contribution to the candidate pool (this is discussed below in the performance assessment section of this report).
4. Currently, REMIDS relies heavily on the operator to discriminate UXO from background in challenging environments. In the last stage of the Yuma data analysis, the operator determined candidates based on the shape of objects as viewed by a particular sensor channel, usually polarization. This raises questions concerning operator training and operator-to-operator variability. (Though it is not currently part of the data reduction flow, it may be possible to automate the shape discrimination algorithm in future implementations.)

In summary, REMIDS can be used to detect known types of surface UXO in areas where there is a direct line of sight from the air to the ground and good distinction between UXO and background spectral returns. REMIDS could be used to locate "potential hot regions" for buried UXO in circumstances when surface debris could be correlated with buried UXO. For example, surface debris at an impact point of a bombing or artillery range may be detected by REMIDS, and this could betray possible buried UXO. In this situation, follow-up detection methods (such as magnetometers) would have to be employed to determine the existence and location of any buried UXO.

Section II of this report provides a detailed technical description of the REMIDS apparatus. Section III is an assessment of the system's performance at Yuma, Arizona, and at Fort Rucker, Alabama. Section IV gives a brief cost assessment.

II. TECHNICAL DESCRIPTION

A. HARDWARE DESCRIPTION

The REMIDS system consists of an active/passive line scanner, real-time processing and display equipment, and navigational equipment.[1] The scanner collects three channels of optically aligned image data consisting of two active laser channels and a passive thermal infrared channel. Figure II-1 shows the common optics for the system. Table II-1 gives the specifications of the system, with information presented for the three spectral channels. The "P channel" senses the reflected light polarized parallel to the transmitted light, while the "C channel" senses the reflected light polarized perpendicular to the transmitted light. The reflectance is essentially the sum of the two channels, while the polarization is the normalized difference. (If a beam of polarized light is incident on a perfectly smooth surface, the reflected beam will possess the same polarization as the incident beam, and in this limit, the return in the C channel will be zero, and the polarization return will be maximum.)

Table II-1. REMIDS Operational Specifications

Digitized Field of View	40 deg
Instantaneous Field of View	1.25 mrad
Scan Rate	350 lines/sec
Scan Width (at an altitude of 130 ft)	29 m
Digitized Samples per Scan Line	710 per channel
Roll Correction	± 15 deg
Laser Type	Nd:YAG
Laser Frequency	1.064 μm
Spectral Channels	
P Channel	1.064 μm
C Channel	1.064 μm
Thermal Channel	8–12 μm

1 J.H. Ballard, R.M. Castellane, B.H. Miles, and K.G. Wesolowicz, *The Remote Minefield Detection System (REMIDS) II Major Components and Operation*, Technical Report EL-92-30, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1992.

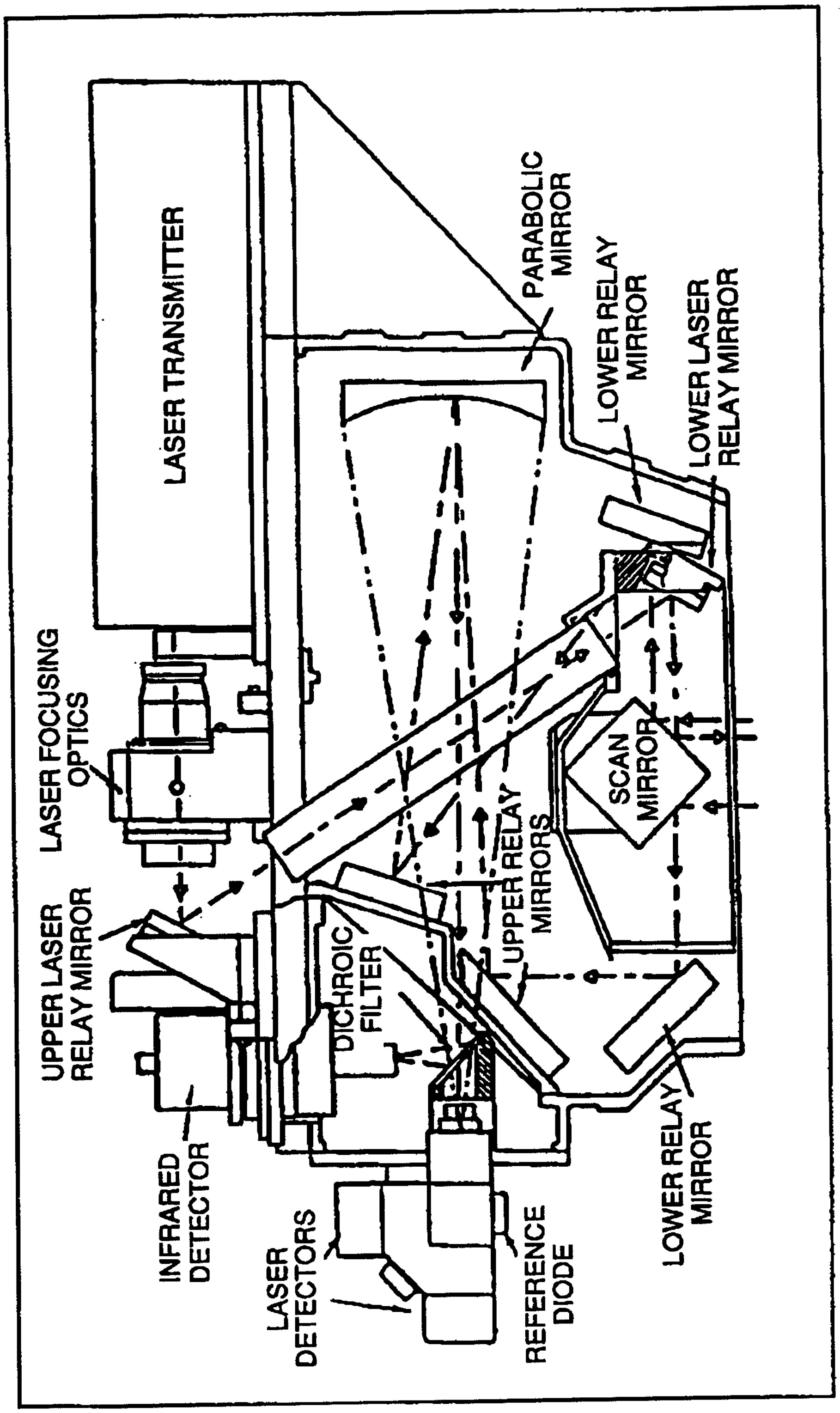

Figure II-1. Hardware Configuration

Using the specifications given in Table II-1, a helicopter flying at 130 ft will produce an instantaneous pixel size of 1.9 in. × 1.9 in.[2] A speed of 32 knots will maintain the aspect of the image being constructed as the data are collected.

B. PHENOMENOLOGY

The REMIDS surface mine/UXO detection algorithm comprises three sequential steps. In the first step, the reflectance, polarization, and thermal returns are used to assign a classification to each pixel. Such a classification provides information on material type and allows for some reduction in the total number of pixels that must be investigated. In the second step, pixels of like classification are joined to form objects. Each object is characterized by its total area, boundary, and distance between its two farthest pixels. At the end of the second step, a table is generated that groups the objects according to location and gives both the spectral and size/shape information of each object. In the third step, the operator decides which objects are targets, using the table generated in the second step to guide his decisions. In the following paragraphs, we discuss each of these stages in some detail, and we provide a quantitative estimate of the role of each step in reducing the false alarms.

1. Stage 1: Spectral Discrimination

The first step in the algorithm, which we call "Stage 1," relies on the fact that different materials will yield different polarization, reflectance, and thermal responses. The reflectance is a function of both the refractive index of the object and its orientation relative to the incident light. In general, metals will have a very high reflectance because they have a complex refractive index, which essentially means that they do not permit the penetration of an electromagnetic wave to any significant depth and thus reflect almost all of the incident light. (In the limit of a perfect conductor, the penetration depth goes to zero and the reflectivity goes to unity.)[3]

The polarization of a material is essentially a measure of its "smoothness," which according to the Rayleigh criterion, is proportional to $\lambda/(h_{rms}\cos\theta)$, where λ is the wavelength of the incident light, θ is the angle of incidence, and h_{rms} is the RMS height of the surface. A material can therefore appear "rough" and hence yield a low polarization

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2 The distance between pixel centers is 1.6 in., implying an overlap between pixels.

3 To be more precise, the reflectivity of a metal is very high as long as the frequency of the light is below the plasma frequency of the metal. Aluminum will reflect light at all optical wavelengths.

return at 1.06 μm, and yet appear "smooth" and yield a high polarization return at 10.6 μm. Hence, one cannot predict the polarization return of a material based on how it looks or feels. One example of this is rust, which one might intuitively expect to have low polarization, but which has been found to yield a significant polarization return at 1.06 μm.

The thermal returns of both ordnance and background will depend upon their thermal properties as well as on the time of day and the weather conditions. The discrimination capabilities of the thermal channel should be best soon after sunrise and sunset, when objects with different thermal diffusivities, surface absorptivities, and emissivities will heat up and cool down at different rates. Near midday, when thermal equilibrium is approached, the thermal discrimination between objects will be more difficult.[4]

The classification of the test site pixels according to their spectral information is a complex process. For each pixel in question, a set of distances, D_i, is defined for each of the possible target material classifications:

$$D_i = \sqrt{\left(\frac{P-<P_i>}{\sigma_{P_i} w_{P_i}}\right)^2 + \left(\frac{R-<R_i>}{\sigma_{R_i} w_{R_i}}\right)^2 + \left(\frac{T-<T_i>}{\sigma_{T_i} w_{T_i}}\right)^2}, \tag{1}$$

where i is the ith classification, angular brackets indicate the mean, and σ denotes standard deviations. The means and standard deviations are obtained from the pixels that come from the targets in the calibration site, and the classifications include only potential target materials. The parameters w_{Pi}, w_{Ri}, and w_{Ti} for the polarization, reflectance, and thermal channels, respectively, are weights that account for the fact that the pixels in the calibration site are not necessarily representative of those in the test site. For example, due to time drift, there should be much more variability in the thermal channel for the test site than for the calibration site. Furthermore, to reduce the complexity, only a few classifications are chosen. Thus, several different materials will fall into one general class, implying greater variability in all three channels for the test site than for the calibration site. Typically, at Yuma, the values of w_{Pi} were chosen to be close to unity because the values of σ_{Pi} were large; those of w_{Ri} were around two; and those of w_{Ti} were at least two, if not greater.

For each test site pixel, the smallest D_i, D_{i_min}, determines its target material classification if D_{i_min} is less than or equal to a threshold value, D_{thresh}. If D_{i_min} exceeds

4 See performance section for the Fort Rucker data, Section III.A, where it is shown that the discrimination capabilities of the thermal channel at 07:31 a.m. are far superior to those at 11:22 a.m.

D_{thresh}, then the pixel is classified as background. D_{thresh} is an adjustable parameter, but it is assumed to be the same value for each material classification. On the other hand, the quantities w_{Pi}, w_{Ri}, and w_{Ti} may vary from one classification to another. Thus, the total number of adjustable parameters is $3N + 1$, where N is the number of target material classifications. We note that by fixing the $3N$ values of w_{Pi}, w_{Ri}, and w_{Ti}, and varying only D_{thresh}, one can build up a receiver operating characteristic (ROC) curve.

The $3N + 1$ adjustable parameters are first chosen to optimize the results from the calibration site. Optimizing the results is a nontrivial task itself and can take as much as one work day to complete. If something does not seem right when Eq. (1) is evaluated for the pixels of the test site (e.g., that pixels covering a very large area are all classified as being the same target material), the operator will vary some of the $3N + 1$ values and repeat the process. Thus, the calibration site provides the operator with initial values for each of the adjustable parameters, but several iterations through the test site data are usually necessary to obtain the optimal set of parameters.

Table II-2 provides the means and standard deviations of P, R, and T obtained from a noontime flight at Yuma Proving Ground on June 26, 1996. The first column gives the number of pixels used to generate the statistics for each material. Those materials marked with asterisks are the target material classifications used in the evaluation of the test site data. The means and standard deviations of all except the dielectric mines were obtained from the calibration site; the means and standard deviations of the dielectric mines were taken from mines in the test site because none were present at the calibration site.[5]

In Table II-2 it may be surprising that the reflectivity of aluminum is lower than that of many other entries. This occurs because the aluminum targets used to obtain these numbers in the calibration site were very small. Thus, edge pixels, which were affected by the background, had a significant effect on the mean. Conversely, large sheets of aluminum yield strong polarization and reflectance returns.

Two other entries warrant further clarification. "Desert pavement" refers to a rocky, blackened crust that covers much of the test site at Yuma and which appears quite

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[5] One might wonder how they were able to classify objects as dielectric mines, given that there were none in the calibration site. It turns out that it was known that one dielectric mine was located at the corner of the test site. This one mine provided about 25–30 pixels of information on P, R, and T. Although the standard deviation on 25–30 pixels is large, this provided a starting point for the analysis of subsequent objects. A few additional objects with similar returns were then picked up and added to the database for dielectric mines.

smooth at 1.06 μm, yielding fairly high polarization returns. "Desert varnish," a background feature yielding even higher polarization returns, refers to the rocks covered with a glass-like sheen. These rocks were located mainly in the wash areas of the test site.[6] At some sites, such as Fort Rucker, the polarization channel alone can provide very good distinction between the targets and the background, but at Yuma this is clearly not the case. The additional information provided by the thermal channel does allow for desert pavement to be fairly easily separated from potential targets, but even with the information from all three channels, desert varnish is very difficult to distinguish from the iron/olive drab paint class.

Table II-2. Polarization, Reflectance, and Thermal Returns at Yuma

Material	# Pixels	$\langle P \rangle$	σ_P	$\langle R \rangle$	σ_R	$\langle T \rangle$	$-T$
desert pavement	21,000	149.91	9.83	82.27	9.24	148.82	15.14
sand and fines	2523	105.17	7.18	166.00	7.97	129.11	5.45
desert varnish	189	180.57	15.27	92.58	12.19	108.93	13.66
iron (oxidized) and olive drab paint *	192	206.98	35.22	58.72	22.43	98.96	17.62
white paint*	15	197.07	36.69	145.67	22.60	73.20	17.50
aluminum*	80	223.30	31.98	101.85	27.95	76.48	33.53
dielectric mines (white plastic)*	180	49.58	20.72	131.66	13.60	90.67	15.93

We note that completion of Stage 1 of the REMIDS algorithm does not require the helicopter to obtain the calibration data, land, process the data, and then obtain the target data. All polarization, reflectance, and thermal data are post processed. Thus, the REMIDS approach is to fly over the calibration site and then fly directly to the real site. In fact, this is necessary for thermal channel calibration data to have any applicability.

The completion of Stage 1 results in a significant reduction of the total number of pixels that might contain targets of interest. Nonetheless, Stage 1 cannot always be relied upon to provide sufficient discrimination from the background to be a viable surface/UXO mine detection system in and of itself. This is particularly true at sites such as Yuma, where the existence of desert varnish resulted in many tagged pixels. Other

6 A wash area is an area where flash floods caused a lot of water of flow through the area. These areas represented roughly 30 percent of the site.

sites may fare better; for example, as shown in Table II-2, sand is easily distinguishable from the targets.

In addition to being site dependent, the reduction in total pixels of interest after Stage 1 is also dependent on the choice of D_{thresh}: a larger D_{thresh} means that more pixels will be tagged as possible targets. The optimal value of D_{thresh} is typically determined after a few iterations through the entire algorithm. Usually, the operator will begin with a conservative value of D_{thresh} and focus on a few difficult-to-distinguish items that he believes are targets. He will then decrease D_{thresh} until those objects are no longer cued. At Yuma, a conservative value of $D_{thresh} = 1.6$ resulted in a reduction in the number of tagged pixels after Stage 1 by about 2-1/2 orders of magnitude, from about 300 million pixels (the total overflown area) to about 600,000.

2. Stage 2: Size/Shape Discrimination

In the second step of the REMIDS algorithm, which we call "Stage 2," pixels of like material classification are joined to form objects. Figure II-2 illustrates an example in which 10 pixels of material class 1 are combined to form an object with an area of 36.1 in^2; a perimeter of 30.4 in.; and a length, defined as the distance between the two furthest pixels, of 10.75 in. (each pixel is 1.9 in. $\times$ 1.9 in.).

3	3	2	2	1	2
4	3	3	1	1	2
2	2	1	1	1	4
2	1	1	1	1	4

Figure II-2. Joining Objects of Like Classification

Software has been developed which performs this step automatically. The operator has the option of specifying how he wants the objects to be formed; for example, he may specify that pixels must be contiguous, or that they need not be. Furthermore, the operator can customize the software so that, in addition to forming objects from tagged pixels, it also filters out many of the objects based on their size and/or shape. For example, an object with a very large area may be rejected, as may one that is too small, too thin, or irregularly shaped.

The level of discrimination provided by the size/shape filter greatly affects the number of objects that are passed on to the operator: too little pre-screening in Stage 2

will result in too many man-hours spent in the final step, but too much pre-screening will result in too many missed targets. Just as with the $3N + 1$ spectral parameters in Stage 1, the optimal level of discrimination used in Stage 2 is ultimately determined after several iterations through the data. At Yuma, for example, it was decided to set the minimum size such that any object smaller than four pixels was rejected. Doing so greatly reduced the number of false alarms due to desert varnish, but at the expense of missing targets smaller than four pixels, such as grenades and Valmeira mines. On the other hand, discrimination based on "irregular shape" was found to be unreliable at Yuma because variabilities in helicopter air speed caused oblong targets to appear to be irregularly shaped. Thus, the only discrimination provided by the size/shape filter in Stage 2 for the Yuma data was that of the minimum size requirement.

The output of the size/shape filter in Stage 2 is a table in which objects are ordered by location (image and scan line). For each object, the material classification and shape information (area, boundary, length) are given. At Yuma, for the iteration in which D_{thresh} was set to 1.6, where 600,000 pixels were passed to the size/shape filter, approximately 20,250 candidate objects were selected. Of these, roughly 20,000 were not targets.

3. Stage 3: Operator Discrimination

The table provided to the operator by the shape/size filter allows him to decide on which images to focus his attention. The operator chooses a spectral channel (usually the polarization channel) and scrolls through the images, viewing several suspicious objects at once. Usually, the man-made ordnance items are easily discernible by eye.[7] Thus, a trained operator is able to identify many of the ordnance items and eliminate many of the false alarms very quickly, without having to study each individual object in great detail. Those objects that the operator cannot identify or eliminate right away are carefully examined in each of the three spectral channels. We note that the operator not only determines whether a suspicious object is a target, he also classifies the target if he decides that it is an ordnance item.

For example, at Yuma, about 95 percent of the roughly 20,000 false alarms were located in the wash areas, which is where most of the desert varnish was located. After carefully examining a few of these objects, the operator realized that most of the items

7 Although man-made ordnance is fairly easily distinguished from natural backgrounds, it should be noted that it may not be easily separated from man-made clutter. The test site at Yuma was a fairly "clean" site, with very little anthropic clutter.

located in these areas were false alarms. Thus, the operator was able to scroll through about 19,000 objects fairly quickly, without having to focus on any of them in detail.[8]

It is clear that the role of the operator is crucial to the success of this system. The operator is involved in each of the three stages, and the total time involved is dictated by his efficacy and skill. For the data collected at Yuma, 1 day was devoted to processing the calibration site data and choosing the initial values of the $3N + 1$ spectral parameters. The analysis of the test site data then took 3 days, the vast majority of which was due to time spent by the operator. Of those 3 days, roughly 60 percent of that time was spent scrolling through images, while the remainder of the time was dedicated to the detailed examination of the roughly 100 suspicious objects that could not be quickly identified.

Given that an area of only 0.5 km^2 entailed 3 man-days of tedious data analysis, an obvious question to address is whether the role of the operator can be automated. Clearly, it should be possible to reduce the amount of time spent scrolling through images, since that time is determined primarily by the level of pre-screening provided by the size/shape filter. At Yuma, this pre-screening was limited to just a minimum size requirement. The developers of REMIDS believe that a robust size/shape filter to allow extensive filtering of the objects before they are passed to the operator can be developed, but that idea has yet to be tested. However, if one opts to rely heavily on a size/shape filter to screen the objects, then one should expect some degradation in performance over that of the current system, because it is unlikely that any computer can provide the level of discrimination of the human eye. For example, the wash areas at Yuma contain many irregularly shaped, varnish-covered rocks. These irregularities, although perceptible to the human eye, would not be so easily distinguished by a computer-based algorithm. In addition, as the operator scans the images, he develops an "intuition" for where the targets and false alarms are most likely to be located. That is, humans possess pattern recognition capabilities that may be difficult to replicate in a computer program. Nonetheless, it seems impractical to rely on the operator to perform the bulk of the discrimination for large areas.

8 There were some ordnance items located in the wash area as well. Some of these targets were discernible based on their size, while others could be distinguished by their spectral signature. Furthermore, compared with the man-made targets, the rocks were often irregularly shaped. However, some targets were lost; small items made of iron or covered in olive drab paint would have been particularly difficult to pick out.

III. PERFORMANCE ASSESSMENT

In this section, we summarize the performance of the REMIDS system at two test sites: Fort Rucker, Alabama, and Yuma, Arizona. The performance at Fort Rucker was superior because the background was mainly grass. In essence, Fort Rucker looked like a "short rough" on which the targets were easily seen, even with just the polarization information. At Yuma, the existence of desert varnish, with its high polarization return, made the targets much more difficult to distinguish, and a 4-pixel minimum object size was required in the analysis. This resulted in a limitation of the size of the objects that could be detected at Yuma (e.g., grenades fall below this size limit).

A. FORT RUCKER RESULTS

Figure III-1(a) shows the performance of the individual spectral channels with respect to the detection of aluminum items, and Figure III-1(b) shows the performance of the individual spectral channels with respect to ferrous and painted surface items. Figure III-1(c) shows the performance of the combined spectral channels for the detection of both aluminum and ferrous/painted targets. Figure III-1(a) shows that the polarization channel alone was sufficient to detect the aluminum ordnance items: 100-percent P_d was achieved with only 15 false alarms in 2,400 m^2. In Figure III-1(b), the performance of the polarization channel in detecting ferrous or painted objects, while not as remarkable as for aluminum, was still quite good, with a P_d of about 95 percent at 15 false alarms. It is clear from Figure III-1(c) that the combination of the three spectral channels yielded excellent performance: greater than 80-percent P_d was achieved with essentially 0 false alarms, while 100-percent P_d was possible with just 20 false alarms. Thus, the spectral filter alone was sufficient at Fort Rucker; no size/shape filter was required, and the operator's role was minimized.

B. YUMA RESULTS

The performance at Yuma is somewhat difficult to assess quantitatively for two reasons. First, insufficient information was provided about target locations. Documentation consisted solely of the contents of each 25 m × 25 m cell, with a rough estimate of

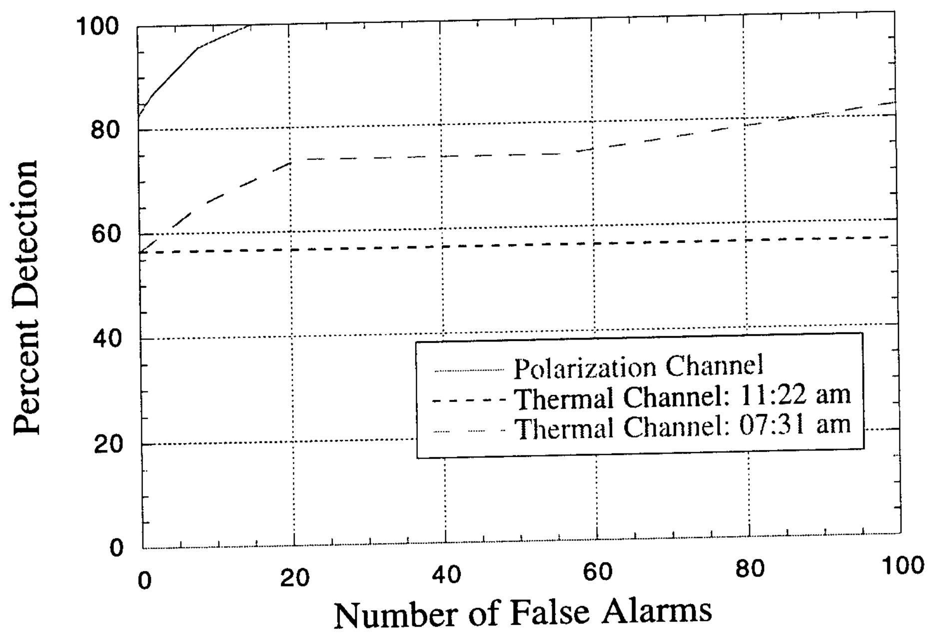

Figure III-1(a). ROC Curve for Fort Rucker: Aluminum Targets Only

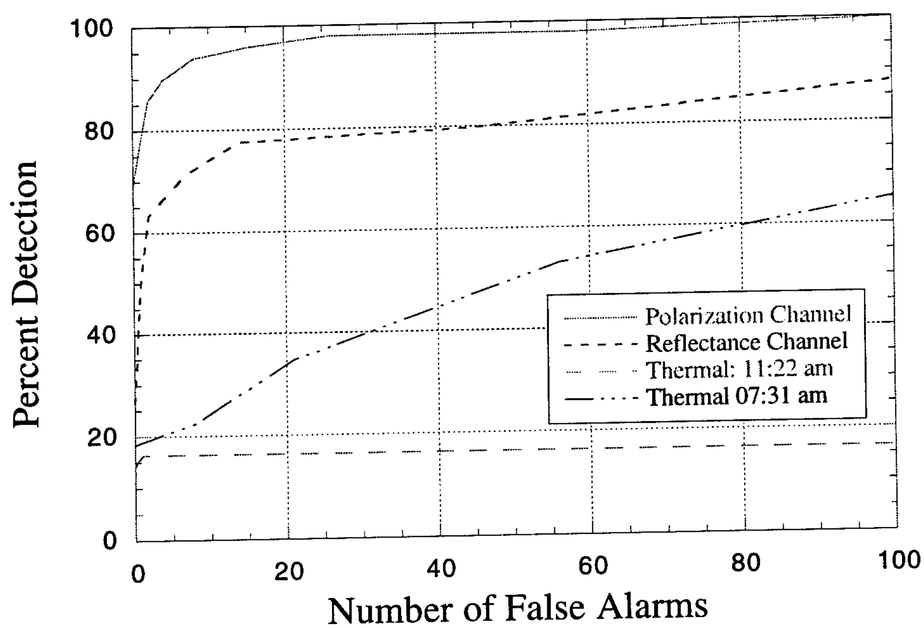

Figure III-1(b). ROC Curve for Fort Rucker: Ferrous and Painted Targets Only

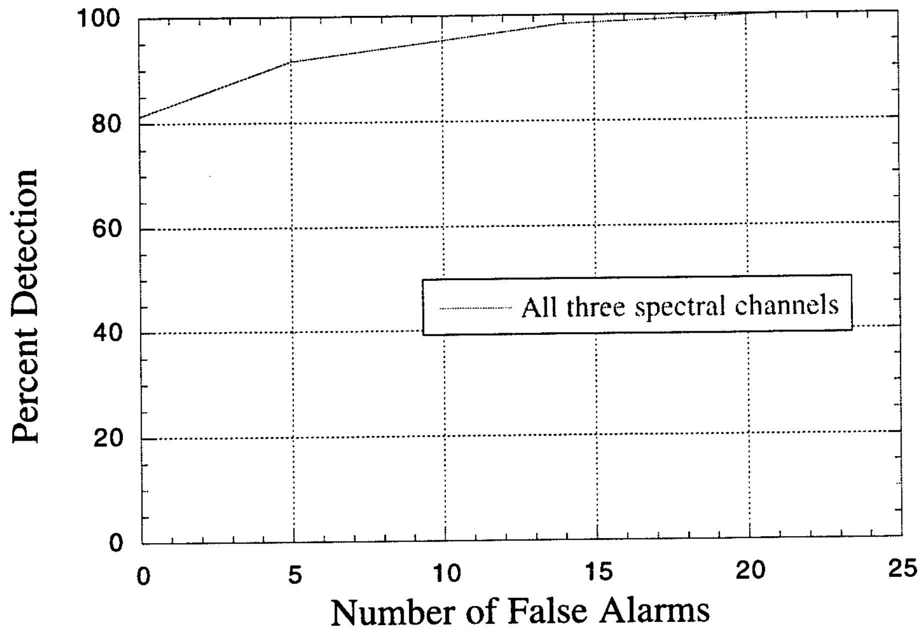

Figure III-1(c). ROC Curve for Fort Rucker: All Targets

the target location(s) within each cell, such as "center" or "northeast corner." For some cells, a hand-drawn sketch was provided. Clearly, the location accuracy of the REMIDS system could not be tested, and detections could not be correlated to targets in cells containing multiple items.

The second, and much more unsettling, reason for the difficulties in evaluating the REMIDS performance at Yuma is that there were uncertainties in the baseline. After the test was conducted, the REMIDS team walked much of the site, taking notes on target types and locations within each cell. They found that for some of the cells, there seemed to be significant discrepancies between what was documented as the baseline and what they actually observed. It was learned that the site is somewhat "dynamic"; that is, items are "borrowed" and moved around. The documentation provided at that time was based on a November 1994 test site survey. The site manager agreed to provide an update of the site baseline, which we received in March 1997. The problem is that it is not known for certain how much the site changed between June 1996, when the test data was taken, and March 1997, when the update to the baseline was determined. Comparing the November 1994 baseline to the March 1997 baseline, we found that of the 132 cells that actually contain some type of ordnance, 20 showed significant differences between the two time periods. It is not known for certain whether the contents of all 20 cells had actually changed, or whether the documentation for some of those cells was incorrect. Either way, however, those 20 cells must be considered questionable.

The REMIDS team attempted to grade themselves as best they could, given these two limitations. However, because they had walked much of the site and had been provided with the November 1994 and March 1997 baselines, it was clearly impossible for them to grade themselves "blindly." Thus, we have attempted to grade the REMIDS system as objectively as possible. We describe our methodology below.

First, in consult with our sponsor, we decided to limit our focus to those targets (1) that are larger than the 4-pixel threshold, and (2) that are of interest to the UXO community. The targets chosen were 500-lb bombs, 2.75-in. rockets, 81-mm mortars, 105-mm projectiles, and 155-mm projectiles. Dielectric mines, although not of interest to the UXO application that was being examined, were also included because they were a particularly easy target for REMIDS to detect,[9] and thus provided a means of estimating the location accuracy of the system. Excluded items included grenades, Valmeira mines, gator mines, volcano mines, and painted mines. All but the last of these were too small to be detected with the 4-pixel threshold.

For each category of interest, we determined in which cells the November 1994 and March 1997 documentation was consistent and clear. In October 1997, we submitted these cells (59 cells altogether, containing 186 targets) to the site manager and requested that he obtain GPS data for each item in each cell.

Upon receiving the requested GPS data in November 1997, however, we discovered that the number of items in 6 of the 59 cells differed from what was documented in March 1997. We had chosen those 59 cells specifically because they appeared according to the 1994 and 1997 documentation to remain constant over time. That the contents of some of the cells seemed to have changed in less than a year caused us to question whether the GPS coordinates provided for the remaining 53 cells were relevant to the June 1996 test. (Certainly, if the items in some cells had changed, the items in others may have been moved around.)

In February 1998 the site manager attempted to determine what had happened in those six cells. He concluded that while two of the cells seemed to have acquired additional items, for the other four cells the original documentation was correct—the surveyors simply had missed some items. We decided to discard only the two cells where the number of items had seemingly increased. In so doing, we may slightly overestimate

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9 See Table II-2. The dielectric mines gave a polarization return that easily distinguished them from all other targets and backgrounds.

the probability of detection, but we estimate that the effect of this error will be less than 1 percent.[10] If we assume that the GPS coordinates of the items in the remaining 57 cells have not changed since June 1996, then the data set is reduced to a total of 168 targets. However, one additional cell was not used because inadequate information was provided by the REMIDS team.[11] Thus, the useful data set was reduced to 167 targets in 56 cells.

To further complicate matters, the REMIDS system experienced problems with its GPS system for 13 of the 59 cells. When the cells in which no GPS data were collected by REMIDS *and* the cells discussed above are excluded, a total of 141 targets remain in the baseline (43 cells).[12]

To estimate the location accuracy of the REMIDS system, we used the GPS data for easy targets: the dielectric mines and the 500-lb bombs. Seventeen mines and two bombs were part of the final target baseline; however, the REMIDS system detected only 15 of the 17 mines. On the other hand, because the REMIDS system often overflew the same target twice, for several of the 17 detected mines and bombs, there were two sets of GPS coordinates. In sum, 27 data points were used to calculate location accuracy.

We determined the location accuracy of the REMIDS system to be 1.55 m in the easting direction and 2.18 m in the northing direction. (The precision of the GPS system used at the site was 0.1 m, according to the site manager.) These values lend support to the assumption that the GPS coordinates in the cells whose contents presumably have not changed are relevant to our analysis. In addition, we found that there was an offset bias in the REMIDS position compared to ground truth: 1.12 m in the easting direction and 0.44 m in the northing direction. We left these offsets in the data during our analysis of the probability of detection because this was the data derived from the test. However, we found that correcting for these offsets only marginally changes the device's detection efficiency.

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10 For example, say a cell had six items in it, but only five GPS coordinates were provided. By grading this cell, we are theoretically giving the REMIDS team six chances at five objects. However, the real effect will be minimal if we assume that the items are randomly placed in the 25 m × 25 m cell.

11 The cell contained one dielectric mine and two painted mines on top of a 4-ft × 4-ft aluminum plate. The REMIDS team noted only that there were three objects on top of a plate, and gave only the GPS coordinates of the center of the plate. Because the dielectric mines were used only to determine the location accuracy of the REMIDS system, we decided that this cell was not needed.

12 One of those 13 cells is also one of the 4 cells where the March 1997 documentation indicated more items than what was surveyed in November 1997. Hence, only three cells having fewer surveyed items than what was documented were in the final target baseline.

We then estimated the probability of detection as a function of radius surrounding the target. To perform this calculation we excluded the dielectric mines, which are not relevant to UXO clearance. Thus, the set of ground truth target data against which REMIDS was graded consisted of 124 ordnance items (seventy 81-mm mortars, twenty-four 105-mm shells, fifteen 155-mm shells, thirteen 2.75-in. rockets, and two 500-lb bombs), distributed among 26 cells. In the remaining discussion, "targets" refer to ground truth ordnance items emplaced at Yuma, while "candidates" refer to REMIDS detections. The analysis flow was structured as follows:

1. Any REMIDS candidate that was both the closest candidate to a target and also within a critical radius, R_{crit}, of the target was matched as a possible detection of the target.
2. A candidate passing the requirement in (1) was considered a detection of a target if it was closer to that target than to all other targets. The matched candidate and target were then removed from their respective lists.
3. Steps (1) and (2) were repeated for the reduced lists of candidates and targets until there were no more targets or there were no more candidates within R_{crit} of the remaining targets.
4. The detection probability of REMIDS as a function of R_{crit} was computed as the number of detected targets for a given R_{crit} divided by the total number of targets (124 in this analysis).
5. In addition to the detection probability, ordnance identification could also be tested in this analysis (the REMIDS team used imagery from the polarization channel). The fraction of the detected ordnance that was correctly identified was measured as a function of R_{crit}.

Table III-1 and Figure III-2 summarize the results of this analysis. Table III-1 gives the breakdown of detection probability versus R_{crit} for each ordnance type. Figure III-2 shows the probability of detection and probability of correct identification as a function of R_{crit} for the combined set of ordnance items. Using Figure III-2 and taking an example value of R_{crit} = 5 m (which is more than a 2 sigma cut, according to our estimate of the system's position resolution), we find that REMIDS detected 76 percent of the target test sample and correctly identified 95 percent of the ordnance detected.

As discussed above, there was an offset bias in the REMIDS position measurement. To determine how an offset correction would affect the detection probability, we ran a Monte Carlo that simulated the device's easting and northing position resolutions, both with the offsets and with a correction that removed the offsets. For the case

Table III-1. Probability of Detection by Ordnance Type

Ordnance Type	P_d @ R_{crit} = 1 m	P_d @ R_{crit} = 3 m	P_d @ R_{crit} = 5 m	P_d @ R_{crit} = 7 m
81 mm	14.3%	57.1%	72.9%	78.6%
105 mm	4.1%	45.8%	75.0%	75.0%
155 mm	0.0%	46.7%	86.7%	86.7%
2.75 in.	0.0%	30.8%	76.9%	92.3%
500 lb	0.0%	50.0%	100.0%	100.0%

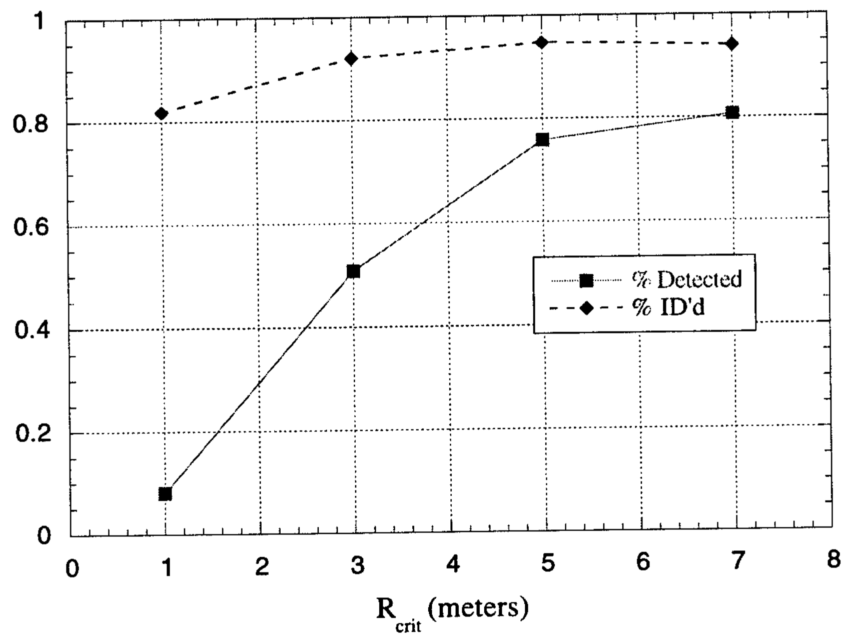

Figure III-2. REMIDS Performance at Yuma

R_{crit} = 5 m, we found that correcting for the offset would improve the detection efficiency by only 2.5 percent over the uncorrected sample. Thus, REMIDS would have achieved about a 78-percent detection probability at R_{crit} = 5 m had the operators corrected the offset bias at the calibration site.[13]

We note that our calculation of P_d does not account for holiday areas, which are those areas not overflown by the helicopter (see Section III.C below). Thus, our value is

13 The effect of the offset bias clearly increases as R_{crit} decreases; for example, at R_{crit} = 3 m, the offset bias correction would yield a P_d of 56 percent, an 11-percent improvement over the uncorrected value of 51 percent shown in Figure III-2.

likely to be a lower bound estimate of the capability of this system. From the "raw" data provided to us, we had no way of determining which targets were not overflown by the REMIDS system, but it is likely that the effect on P_d is only a few percent.[14]

To estimate the false-alarm rate (*FAR*), we looked at three regions of the site that contained no targets. The area of the first region was 0.073 km^2, and the REMIDS system declared a total of three targets in that area, identifying all three as gator mines. This translates into a *FAR* of 41 per km^2. The second region was 0.049 km^2 in area, and the REMIDS system declared two targets, one a gator mine, and the other UXO scrap. This also yields a *FAR* of 41 per km^2. The third region was a much smaller area of only 0.028 km^2, and in this region, the REMIDS system declared no targets. We conclude, therefore, that the REMIDS system, with its three-stage analysis, yields a very low false alarm rate. We emphasize, however, that the false alarm rate would have been much higher if only the first two analysis stages had been employed (spectral and size/shape), because the operator played a crucial role in recognizing and eliminating false alarms.

In addition to its potential use in identifying individual UXO targets, REMIDS also has potential as a large-area search system used to determine which sections of a large area must be thoroughly investigated, which sections will require only minimal investigation at isolated spots, and which sections can be declared ordnance free.

To illustrate this point, Table III-2 shows the number of false alarms per square kilometer after stages 1 and 2 were completed for a number of different ordnance-free sites at Yuma and Fort Rucker. These sites represent a variety of backgrounds:

- Drop Zone—a Yuma sandy/silt area that is clear of vegetation (this area is the practice drop zone for parachute training)
- Indian Wash—a Yuma sandy/silt area with small foliage (contains desert varnish)
- Mitri Lake—a Yuma area that is a bank on Mitri Lake with dense vegetation
- Pavement Dyno—a Yuma area that is a pavement-covered area
- Sand Dyno—a Yuma area that corresponds to a very loose sand area[15]
- Plowed Field—a Fort Rucker silt area that is a newly plowed field

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14 The REMIDS team estimates that the overflown area was about 96 percent of the total area. If we assume a random distribution of targets, then we might reasonably expect a P_d of 0.76/0.96 = 79 percent, relative to the overflown area.

15 This sand is not indigenous to the area and is not the same sand as that appearing in Table II-2.

Table III-2. Background False Alarms per km² Using Stages 1 and 2 Only

D_{thresh}	1.6				1.0				0.7			
Target Type	Pl	WP	Al	FeOD	Pl	WP	Al	FeOD	Pl	WP	Al	FeOD
Background type												
Drop Zone 0.0222 km²	500	0	0	0	500	0	0	0	0	0	0	0
Indian Wash 0.0181 km²	0	0	0	4,500	0	0	0	500	0	0	0	0
Mitri Lake 0.0189 km²	20,000	0	0	0	10,000	0	0	0	2,500	0	0	0
Pavement Dyno 0.00389 km²	0	1,000	0	14,000	0	1,000	0	7,000	0	0	0	1,500
Sand Dyno 0.00601 km²	0	0	0	0	0	0	0	0	0	0	0	0
Plowed Field 0.00566 km²	0	0	0	0	0	0	0	0	0	0	0	0
New Crop 0.00825 km²	0	0	0	0	0	0	0	0	0	0	0	0
Short Vegetation 0.00554 km²	0	0	0	0	0	0	0	0	0	0	0	0

Note: Pl = plastic
WP = white paint
Al = aluminum
FeOD = oxidized iron and olive drab paint

- New Crop—a Fort Rucker area that is covered with new crop vegetation
- Short Vegetation—a Fort Rucker area that has field vegetation shorter than 2 inches.

For each site, information was gathered for a single pass only; hence, the total area covered in each case was much less than a square kilometer (see the table). Table III-2 was generated for D_{thresh} values of 1.6, 1.0, and 0.7. The target types are plastic (Pl), white paint (WP), aluminum (Al), and oxidized iron and olive drab paint (FeOD).

Table III-2 indicates that the REMIDS algorithm would correctly predict half of these sites to be completely ordnance free. These results, which are consistent with the discussion in Section II and the performance at Fort Rucker, suggest that REMIDS may

be very successful in assessing large tracts of sandy or grassy land, with only minimal operator participation.[16]

For large tracts of land similar to the four sites in Table III-2 showing a significant number of false alarms, further analysis (Stage 3, Operator Discrimination) may be required. On the other hand, in the case of the Drop Zone, the false alarms were located almost exclusively around the perimeter of the site. Thus, REMIDS would have correctly declared most of the site to be ordnance-free.[17] Furthermore, the false alarms in the white paint class in the Pavement Dyno were caused by the white striping on the pavement and therefore could easily be eliminated by an operator. On the other hand, those alarms in the oxidized iron/olive drab class in the Pavement Dyno would not be so easily discarded: it is thought that they were generated by machinery and vehicle parts, because a garage station was located near the site. As expected, the Indian Wash generated false alarms in the iron-oxide/olive drab class.[18] At Mitri Lake, which had the most false alarms, the false alarms were scattered over much of the site; it is believed that they were caused by tree bark (the paper-like bark of birch trees probably yields a polarization return similar to plastic). Clearance of large tracts of land similar to Mitri Lake would probably not be possible without the Stage 3 analysis.

C. LESSONS LEARNED

There were two major lessons learned during the testing of the REMIDS system. First, complete coverage is not likely to be achieved without a global positioning system (GPS)-aided flight guidance system. At Yuma, the helicopter flew over only about 96 percent of the site, and therefore, a P_d of 100 percent was not achievable. There are four main factors that determine the amount of site coverage: (1) the amount of overlap between adjacent passes, (2) the direction of the wind gusts, (3) the intensity of the wind gusts, and (4) pilot reaction time to the wind gusts. An increase in overlap does not guarantee full coverage because wind gusts can divert the helicopter off course.

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16 The only way in which operator skill would be introduced in this application would be in determining the $3N + 1$ parameters for the spectral filter.

17 It is thought that the false alarms located around the perimeter may have been caused by man-made items such as parachutes or food container refuse.

18 Note that the number of false alarms in the Indian Wash area was not that high. This is because the desert varnish mainly collects on the edges of a wash area and not in the wash itself; the helicopter passed over the center of the wash area.

Second, it is necessary to correct for image shifting due to the rotation frequency of the helicopter blades. This image shifting occurred at approximately 17 Hz; however, the frequency was not consistent enough to attempt a correction based directly on the frequency. In addition, the magnitude of the shifts varied greatly throughout the image—from 0 to 5 or 6 pixels. Therefore, corrective shifts had to be calculated on a localized basis from the images itself. Previous experience had shown that line-to-line correlation could be effective in correcting these types of problems. By shifting one of two adjacent lines by various amounts and computing the correlation of each shifted line with the unshifted line, the optimal shift between the two lines could be identified. The major drawback of this approach is that strong linear features in the terrain bias the correlations. For example, a road that runs diagonally across the image will result in "corrections" that cause the road to run vertically down the image, drastically distorting the image. This problem was alleviated by normalizing the shifts so that they summed to zero over each 20-line segment of the image. The steps in the correction algorithm are the following:

1. Calculate the correlation between each line and the preceding line with shifts of −2, −1, 0, 1, and 2 pixels.
2. Use the correlation values from step 1 to calculate a subpixel shift between each pair of lines.
3. Calculate the average line shift over each 20-line segment of imagery. Twenty-line averages were used because the number of lines in 1 cycle of the vibration was approximately 20.
4. Normalize the shifts for each line by subtracting the 20-line average shift for the segment containing the line. This yields a net total shift of 0 for each 20-line segment and removes any bias of the terrain in one direction.
5. Apply the normalized shifts to the image.

Figure II-3(a) shows a sample image before the correction, and Figure II-3(b) shows the same image after correction.

D. LIMITATIONS OF THIS SYSTEM

A key limitation of the REMIDS system is that its performance is highly site dependent. The grassy background at Fort Rucker enabled the system to easily pick out the targets based on their spectral information alone; no shape filter was needed. On the other hand, the desert varnish at Yuma rendered the spectral information insufficient.

Figure II-3(a). A Sample Image before the Correction

Figure II-3(b). A Sample Image after the Correction

It became apparent from the Yuma data that the shape filter and especially the target-recognition capabilities of the operator will play a critical role in this technology for any backgrounds with spectral returns close to those of the targets of interest.

In addition to the fact that some backgrounds render discrimination based solely upon spectral information impossible, there are other physical limitations of the system. For this system to work, the laser must have a line of sight to the surface ordnance items. Thus, broad-leaf vegetation, trees, and understory can pose a laser-penetration problem. Dust-covered ordnance may also be difficult to see; even if the dust covering is such that some of the surface is exposed, the classification of the UXO may be difficult. Finally, the system cannot be used when the targets are covered with snow.

The REMIDS system is more effective if samples of materials expected at the site are available to calibrate the spectral classes. The polarization returns for painted objects can vary greatly depending upon the type of paint, for example. Also, the polarization and reflectance returns will vary with ordnance age. For some material types, this is not a big problem; rust, for example, still yields a fairly high polarization return. However, the polarization and reflectance returns of oxidized brass are much lower than those of new brass, and this caused some problems at Yuma. Specifically, snake-eye fin assemblies that were at the Yuma site were made of painted brass. The nonweathered fin was an easy item to detect, but the weathered fin was not associated with any of the material classes and hence went undetected.

If this system were used at a site where only limited information about the expected ordnance items was available, then the performance would likely be below that exhibited at Fort Rucker and at Yuma. In principle, one could try to include as many material classes as possible; there is no limit to the number of material classes used in the spectral filter. In practice, however, the more classifications, the more complex the processing, since the total number of free parameters used in the spectral filter is $3N + 1$, where N is the number of spectral classifications. Hence, to optimize the performance of this system, one should find out as much as possible about the UXO at the site in question, particularly the material composition and age of the ordnance.

E. CONCLUSIONS

Based on these results, it is clear that the performance of this system is site dependent. If the background is grassy as at Fort Rucker, it is quite likely that a P_d of at least 90 percent is achievable with very low false-alarm rates using only the Stage 1

analysis. At sites such as Yuma, such performance is probably impossible with just the spectral information. However, fair-to-good performance can be expected once the size/shape filter and operator filter are employed, *if* one is willing to accept that the system cannot be used to detect all ordnance. Specifically, if there is a high probability of large numbers of false alarms, a minimum size requirement will probably be necessary, and the system will therefore not be able to detect items smaller than this minimum size. Thus, if REMIDS were used to detect surface UXO larger than 4 pixels at a site such as Yuma, a P_d of about 76 percent with a very low FAR might be expected, assuming a declaration radius of 5 m. (We note again that this number is probably a lower-bound estimate of P_d, because holiday areas were not accounted for in the calculation.)

On the other hand, in realistic scenarios with large areas, the methodology adopted at Yuma would have to be modified, because too much emphasis was placed on the ability of the operator to discriminate the ordnance items. This modification would entail a more sophisticated shape/size filter to pre-screen the objects, so that the operator could complete his role in a reasonable amount of time. It is not known whether transferring the bulk of the discrimination from the operator to the size/shape filter will result in similar performance as that achieved at Yuma, although it is likely that at least some degradation in performance may be expected (see discussion in II.B.3).

Although we cannot state for certain whether this system can be relied upon to predict individual ordnance types with high P_d and low P_{fa} over large areas with potentially challenging backgrounds, we do feel reasonably confident in claiming that this system has potential in a large-area search mode of operation, with minimal operator participation, especially for grassy or sandy sites. It is often the case that when large tracts of land must be cleared of UXO, a significant portion of that land is already clean, but it is not known which portions are clean and which must be cleared. From the discussion in Section III.B, it is evident that the REMIDS system could play a valuable role in clearing large tracts of land by determining quickly which areas are already likely to be clean and which warrant further investigation. This analysis can be performed solely with the spectral filter and the crude size filter employed at Yuma. More sophisticated size/shape filters will render this system even more effective in screening large areas. In any case, because the spectral and shape/size filters do not require much operator input, this screening can be performed quickly and reliably.

IV. COST ASSESSMENT

The following estimate includes the cost of transporting the REMIDS system to and from the site in addition to the costs of collecting 18 hours of flight data.

1.	Equipment installation and calibration	$95,000
2.	Helicopter Support (includes ferry hours to transport the helicopter and its crew)	$120,000
3.	Ground Equipment Transportation, Setup, and Rental	$18,000
4.	Data collection (includes the cost of flying the helicopter and the crew for 18 hours)	$48,000
5.	Data analysis on site (roughly 3 man-months, includes per diem and transportation)	$68,000
	Total	$349,000

The first item includes the installation of the flight-aided digital global positioning system (DGPS). The use of regular DGPS will reduce the cost of the first item to $50,000 but it will increase the fourth item to $70,000, for an overall cost of $326,000. The lack of flight-aided DGPS will limit the ability to cover areas missed on the initial flyover (holiday areas), and it will also necessitate the use of visual markers on the ground for the desired flight lines.

The area that can be covered in 18 flight hours will depend upon the profile of the data collection flights (i.e., altitude and forward speed), as well as the chosen flight path. For example, if the 0.5 km × 1 km site at Yuma is traversed crosswise (i.e., using 500-m passes), then during 1 flight hour, only about 15 minutes is dedicated to actual data collection. The rest of the time is spent making turns and lining up for the next pass. In this case, with a pixel resolution of 1.9 in. × 1.9 in., 1 flight hour yields about 100 acres of coverage. On the other hand, if the site is traversed lengthwise, the coverage will be much greater; estimates provided by the REMIDS team are on the order of 300 acres per flight hour. A lower resolution will also allow for more coverage per flight hour; for example, decreasing the resolution to 4.5 in. × 4.5 in. will yield about a factor of 5 increase in area coverage per flight hour.

In addition to the above, a cost estimate for this system should include the time for operator training. The developers of this system estimate that at least 3 man-months will be needed per operator.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
June 1998

3. REPORT TYPE AND DATES COVERED
Final—August 1997–June 1998

4. TITLE AND SUBTITLE
Assessment of the REmote MInefield Detection System (REMIDS)

5. FUNDING NUMBERS
DASW01-94-C-0054/
DASW01-97-C-0056
T-AM2-1528

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Institute for Defense Analyses
1801 N. Beauregard St.
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8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Document D-2158

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ESTCP Program Office
901 N. Stuart Street, Suite 303
Arlington, VA 22203

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 180 words)***

This report describes the REmote MInefield Detection System (REMIDS) developed by the U.S. Army Engineer Waterways Experiment Station to detect surface UXO. REMIDS collects three channels of optically aligned image data consisting of two active laser channels, one polarized reflectance and the other total reflectance, and one passive thermal infrared channel. The system also incorporates onboard sensor data recording and post-processing insertion of differential Global Positioning System (GPS) coordinates. The principle behind REMIDS is to enhance the discrimination of surface UXO by relying on multiple signatures: surface UXO may exhibit a unique *combination* of reflectance, polarization, temperature, and footprint (shape), compared to natural objects in the UXO's surroundings. In addition to a description of the phenomenology of REMIDS, an evaluation of the performance of the system at the Yuma Proving Ground (Arizona) and at Ft. Rucker (Alabama) is presented. Items used at those sites included mines, rockets, mortars, projectiles, and bombs. Performance curves (P_d vs. P_{fa}) are presented for both test sites. Furthermore, measurements at several ordnance-free sites were obtained at Yuma to assess the potential use of REMIDS as a large area search tool.

14. SUBJECT TERMS
electro-optical detection, infrared detection, mine detection, UXO detection

15. NUMBER OF PAGES
38

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102